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impression of a woman of extraordinary good sense, and of uncommon powers of mind; whose letters, embracing a wide variety of subjects, are as truly valuable as those of any other writer, and likely to be of as permanent interest, and to afford as lasting gratification; but especially of a woman of great strength of character, formed by religious principle and penetrated by religious sentiment, the vital principle of whose moral being was faith in God and immortality, whose sympathies were warm and diffusive, and who was full of disinterested kindness.

ART. VI. — 1. *Leçon sur la Statique Chimique des Etres Organisés, Professée par* M. DUMAS, *pour la Clôture de son Cours à l'Ecole de Médecine.* Paris: Fortier, Masson, & Co. 1841. 8vo. pp. 48.

2. *The Chemical and Physiological Balance of Organic Nature; an Essay.* By J. DUMAS and J. B. BOUSSINGAULT, Members of the Institute of France. [An English Translation of the Third French Edition.] London: H. Bailliere. 1844. 12mo. pp. 156.

3. *Lectures on the Applications of Chemistry and Geology to Agriculture.* By JAMES F. W. JOHNSTON, F. R. S., etc. Edinburgh: Blackwood & Sons. 8vo. New York: Wiley & Putnam. 12mo.

4. *A Treatise on the Forces which produce the Organization of Plants; with an Appendix, containing several Memoirs on Capillary Attraction, Electricity, and the Chemical Action of Light.* By JOHN WILLIAM DRAPER, M. D., Professor of Chemistry in the University of New York. New York: Harper & Brothers. 1844. 4to. pp. 216.

We need not inform our readers, that the subjects with which these works are occupied have recently excited much attention and interest. Few strictly scientific treatises have been so generally read in this country as Professor Liebig's volumes on chemistry, in its applications to vegetable and animal physiology. They have not only been repeatedly issued in rival editions by respectable publishers, but the two comely octavos have been transformed into a couple of almost illegible pamphlets, and widely scattered over the land in the form of "cheap literature." We are relieved, therefore, from the misgiving we might naturally feel at placing works with such uninviting scientific titles at the head of our article; and may, without hesitation, proceed to give some account of them.

Professor Dumas is at the head of the French school of organic chemistry. His eloquent discourse on the prominent features of the life of plants and animals, considered under a chemical point of view, was pronounced at the close of his annual course of lectures at the School of Medicine, in the spring of 1841, and it forms a spirited summary of the principles which he had very fully developed during that session, and in preceding years. To the second edition was appended a series of explanatory and historical documents; and these were increased in the third, of which the second work on our list is an English translation. A portion of the appendix, and of the researches upon which these striking generalizations are based, was furnished by the zealous fellow-laborer of Dumas, M. Boussingault, whose name is accordingly associated with his own upon the title-page.

Professor Johnston's volume consists of a full series of lectures, the greater part of which were actually addressed to an audience of practical agriculturists, the Farmers' Club of Durham, England; and we are free to say, that, for the amount of useful matter it comprises, and for just scientific views happily and plainly applied to practical use, the work is unrivalled. It embraces a wider field, and enters into more specific details, than the plan of Professor Liebig's works permitted; and is, therefore, more directly available to the cultivator of the soil, whose wants it was especially intended to supply. Although addressed not to men of science, but to farmers, it will bear the test of scientific criticism, as such a work should do, perhaps above all others. One should be a complete master of a science, in order safely to teach its applications to practice. No idea is more fallacious, than that those who know little of a science may yet be qualified to write elementary books for those who know nothing. Those who have but a pittance of scientific knowledge had best "give God thanks, and make no boast of it; and as for their writing, let that appear when there is no need of such vanity."

Professor Draper's large and handsome quarto volume is a work of higher pretensions. It is addressed to the learned, and purports to contain important discoveries in the domain of science.

> "The time has now arrived," he announces in his Preface, "when both vegetable and animal physiology *are to have* their foundations laid on chemistry and natural philosophy, the only basis which can elevate them from *their present deplorable position* to that of true sciences. It is with this impression, that the explanations which I have given in this book, of the mode by which light acts in determining organization, and of the mechanical causes by which such organized matter is transmitted from point to point of living systems, (for these are the leading facts which this work is designed to illustrate,) are offered to the attention of chemical philosophers."

The italics are our own. The preface bears the date of October 1, 1844. It is, of course, incumbent upon us to give our readers some general account of these discoveries. The problem which Dr. Draper has undertaken to investigate is a very interesting and fundamental one; and towards its elucidation much has already been done, and more may be expected from chemical and physical research. So imposing a volume of original researches demands our special attention. But as our author, writing much in the manner of a popular lecturer, and taking nothing for granted, although ostensibly addressing "chemical philosophers," seldom distinguishes between that which is to be deemed original, and that which mere sucklings in science might be supposed to know, it may be worth while, in the first place, to favor our unlearned readers with a sketch of those general conclusions, which the vegetable physiologists and chemists had already obtained. This we shall attempt to do, after our own fashion, taking the vegetable kingdom as our starting-point, and pursuing the course which, in our view, leads to the most natural and clear exposition of the general phenomena and results of vegetation, considered under a chemico-physiological aspect.

Of what, it may be asked, do plants essentially consist? Whence do they obtain the matter which enters into their composition, — that is, their food? And what changes does the plant impress upon the materials it feeds on? The answer to these questions brings to view the reciprocal relations and influences of the mineral, vegetable, and animal kingdoms, and enables us to comprehend the office of plants in the general economy of the world.

The food and the elementary composition of plants stand in a necessary relation to each other. Since it is absurd to suppose that vegetables possess the power of creating any element, whatever they contain must have been derived from without. Their composition, therefore, indicates their food. If we have learned the chemical composition of a vegetable, and also what it gives back to the soil and the air, we know what it must have derived from without; that is, its food. Or, if we have ascertained what the plant takes from the soil and air, and what it returns to them, we have learned its chemical composition, — the difference between these two. And when we compare the nature and condition of the materials which the plant takes from the soil and the air with what it gives back to them, we may comprehend the influences of vegetation upon the mineral kingdom.

If we consider, then, the materials of which plants are composed, we shall learn what their food must necessarily contain. These materials are of two kinds; the difference between which may readily be made apparent. Every one knows that water, that universal solvent, as it percolates the soil, dissolves a portion of the various earthy matters it meets with. These, being drawn into the plant with the water which the roots imbibe, are at length deposited either in the wood or the leaves, from which the greater part of the water at length escapes by evaporation; they form the ashes which are left on burning a leaf or a piece of wood. Now, although it is true, that these earthy or mineral matters are often turned to account by the plant, and although some of them are necessary in the formation of certain products of certain plants, — as, the flinty matter which gives needful firmness to the stalks of wheat, and the phosphate of magnesia, the iron, &c., which always exist in the grain, — yet none of them are essential to simple vegetation, which may, and often does, proceed as well without them. These materials, whose presence is in some sort accidental, may be called the *earthy*, *mineral*, or *inorganic* constituents of plants.

But if we analyze the newly formed tissue of plants, or any vegetable substance, such as a piece of wood, after this incrusting mineral matter has been chemically removed, we find it invariably composed of either three or four elements; elements which are indispensable to vegetation, and which make up, at least, from eighty-eight to ninety-nine *per cent.* of every vegetable substance. These are the *universal, organic* constituents of plants.

These we now consider, leaving the mineral materials entirely out of view for the present. The four essential organic elements of plants are *carbon*, *hydrogen*, *oxygen*, and *nitrogen*. The proper vegetable structure, that is, the substance of the cells and vessels, uniformly consists of only three of these simple elements, namely, *carbon*, *hydrogen*, and *oxygen*. These are absolutely essential and universal; while the fourth, *nitrogen*, though perhaps always present, is only requisite in the formation of certain very important products.

These four elements must be furnished by the food upon which the vegetable lives; they must be drawn from the soil or the air. Since the leaves, as ordinarily situated, can imbibe air or vapor only, and the hygrometric tissue of the rootlets is specially adapted to the absorption of liquids, refusing admission to solid particles, the food of the plant must be received in the gaseous or liquid form, chiefly in the latter. But in whatever form imbibed, the great vehicle of the plant's nourishment is evidently *water*, which as a liquid bathes its roots, and in the state of vapor continually surrounds its leaves. The question, therefore, naturally arises, Is water itself the food of plants?

Water is composed of oxygen and hydrogen. It may, therefore, furnish two of the plant's essential elements. It must furnish the principal part of the hydrogen; for this element does not exist, in a separate state, either in the soil or in the air, nor in any form, (with an exception that may be left out of the general view,) unless as one of the components of water. And reasons, which will hereafter become apparent, also show that nearly all the oxygen which actually enters into the composition of the plant must be derived from the water which it so freely imbibes.

But water can never furnish what it does not itself contain. It has no carbon in its composition, no nitrogen.

Therefore, *pure water*, though indispensable, is insufficient for the nourishment of plants. Yet if the water, which so copiously filtrates through the leafy plant, actually contains even a minute quantity of the two remaining ingredients, carbon and nitrogen, in such a form that they may be detained in the plant when the superfluous water is exhaled, abundant provision for the food of the vegetable would thereby be afforded ; for, however diluted, the plant may condense and accumulate it to the requisite extent, just as the extremely minute portion of earthy matter, which the water holds, accumulates in the leaves and wood. The question, then, recurs in this form : Does the water, which the plant actually imbibes, contain a quantity of these remaining elements ? Though pure water cannot, yet may not rain-water furnish the needful carbon and nitrogen ?

Nearly seventy-nine *per cent.* of the atmosphere consists of nitrogen gas, in an uncombined state ; that is, merely mingled with oxygen. Now, as this gas is to a certain extent absorbed by water, every rain-drop that falls through the air must bring with it a minute portion of nitrogen ; and this is necessarily imbibed with the water which the roots take in. Accordingly, free nitrogen gas is always found in growing plants. There is, besides, a compound of nitrogen, which is always formed when any animal, and almost any vegetable, substance decays, and which is found to be especially adapted to the nourishment of plants, namely, *ammonia*, or *hartshorn*, — a compound of hydrogen and nitrogen. We know that ammonia exists in the air, though in quantities so minute as to be inappreciable to our senses ; since, being very volatile, it must continually rise from decaying animal and vegetable substances. We readily apprehend why it does not accumulate, in the progress of time, so as to become perceptible ; for it is extremely soluble in water, as well as all its compounds, and is therefore greedily absorbed by aqueous vapor, and thus washed out of the atmosphere, as it were, and brought down to the surface by rain. The chemists can accordingly detect its presence in all rain-water. In this form, as ammonia and its volatile compounds, nitrogen must continually be presented to the roots of plants. That the roots actually absorb it may be inferred from the familiar fact, that plants grow most luxuriantly when the soil is supplied with those substances which yield much ammonia, such as most manures. And finally, ammonia, as such, may be detected in the juices of almost all plants.

Rain-water, therefore, contains the third element of vegetation, *nitrogen*, — drawn from the air, both in a separate form, and in that of ammonia. But what is the source of the remaining constituent, *carbon*, of which plants must have a copious supply, since it forms by far the largest portion of their bulk? If we obtain the carbon of a leaf or a piece of wood, separate from the other organic elements, — which is done by charring, that is, by heating it out of contact with the air, so as to drive off the oxygen, hydrogen, and nitrogen, — although we necessarily lose a part of the carbon in the operation, yet what is left perfectly preserves the shape and bulk of the original material, even of its most delicate cells and vessels. From forty to sixty *per cent.*, by weight, of the original body remains in the form of carbon or charcoal.

Now, all the other elements of plants are gases in their natural state, actually existing in the air, from which they are drawn and presented to the roots in the form of rain-water; while carbon is a solid, absolutely insoluble in water. In what form can it be employed by the plant, which imbibes fluids only? The chief, if not the only, form in which a fluid compound of carbon is naturally presented to the plant is that of *carbonic acid gas;* which consists of carbon and oxygen. This gas makes up, on an average, one two-thousandth of the bulk of the atmosphere; from which it may be directly absorbed by the leaves. But it is freely soluble in water, up to a given extent, and so must be carried down by the rain, and imbibed by the roots. The carbonic acid of the atmosphere is clearly the great source of carbon for vegetation.

The mineral world is made up of a large number of elementary bodies, and their compounds are multiplied almost to infinity; but only three or four of these are concerned in the general phenomena of vegetation. The air, water, and carbonic acid are the few materials upon which organic nature universally operates. The atmosphere that surrounds us — considering water in the state of vapor to form a component part of it — contains all the essential elements of plants, and contains them in the best, if not the only available, form; namely, in a fluid state. It furnishes water, which is not only food itself, but is the vehicle of the others; as it brings to the roots what it has gathered from the air, that is, the needful supply of nitrogen, (either separately or in the form of ammonia,) and of carbon in the form of carbonic acid.

It is worthy of particular notice, that the whole *proper food* of plants — the water, the nitrogen, and the carbonic acid — *may be* absorbed by the leaves directly from the air, in the state of gas or vapor. That certain plants may derive adequate sustenance in this manner is evident from such cases as that of the common Orpine, or Live-for-Ever of the gardens, — a branch of which, thrust into a crevice, or pinned to a bare shaded wall, will usually live and grow for the whole season. That most plants actually take in a portion of their food in this way, or at least may be made to do so when all other supply is arrested, is well known to vegetable physiologists. And that one class of vegetables, the ***Epiphytes***, or Air-plants, as they are appropriately called, must draw their whole sustenance directly from the air, is perfectly certain; for they have no connection with the soil. But leaving peculiar cases and subordinate arrangements out of view, it is plain, that the general office of leaves is to elaborate rather than to absorb nourishment. As a comprehensive statement, we may say, that plants, though they *derive their food from the air*, *receive it through their roots*. The aqueous vapor, condensed into rain, and bringing with it to the ground a portion of carbonic acid, and of nitrogen or ammonia, thus conveys the appropriate food of the plant to the rootlets. Absorbed by these, it is carried through the stem into the leaves, where the now superfluous water is restored to the atmosphere by exhalation; while the residue is converted, by a most refined chemistry, into the proper substance of the vegetable.

The water exhaled, laden in its circuit with a new supply of carbonic acid and nitrogen, may in time be again absorbed by the roots of plants, again exhaled, and thus follow its ceaseless round. This is beautifully illustrated by the cultivation of plants in close glazed cases, where they are made to flourish for a long time with a very limited supply of water, every particle of which, except the small portion actually decomposed by the plant, must have passed repeatedly through this circulation. This vegetable microcosm truly exhibits the actual relations of water and air to vegetation in the great world. It is well known, that, if all the aqueous vapor which the atmosphere can hold at any one time were to fall at once in the form of rain, it would scarcely amount to five inches in depth over the whole surface of the globe. But certainly the atmosphere, taken altogether, never does contain half the quantity of water it is capable of holding; so that all the aqueous vapor which it actually holds at any one time would not amount to more than two inches of rain over the whole of the earth's surface.

Now, the actual fall of rain varies, in different latitudes, from 13 to 150 inches *per annum*; and the mean fall of rain over the whole earth is estimated at over thirty inches. Consequently, the water which falls in rain is, on an average, reëvaporated and rained down fifteen times in the course of a year. This is exclusive of the dew, by which the alternate evaporation and condensation is daily repeated on a smaller scale, and whose gentle action, though less striking, is scarcely less beneficial. For a simple physical law causes the dew to bestow its silent favors where they are most required, — upon the grass-plot and the cultivated field, — not upon the unrequiting rock, the naked sand, or the trodden highway, where there is no vegetation to nourish. Even rain, on a great scale, is distributed much in the same manner. It is denied to the arid desert, and most plenteously poured upon regions clothed with forest. Nor do we mistake the effect for the cause; for, once established, cause and effect are here reciprocal. "To him that *hath* shall be given."

An obvious consequence of this perpetual circulation of water is, that the atmosphere is repeatedly *washed* by the rain; and those vapors are washed out, which otherwise, by their accumulation, would ultimately prove injurious to animals; such, especially, as carbonic acid and ammonia, which are continually imparted to the air by animals, and so conveyed to the roots of plants, which they are especially adapted to nourish. Nor should it be overlooked, that the thunder-storm, as well as the gentle dew and the refreshing shower, works for good in the beneficent arrangements of the Creator. The flashes of lightning, that "dart from the storm-cloud and furrow vast fields of air," engender from aerial elements a quantity of the nitrate of ammonia, — the most potent of manures, the most concentrated vegetable food, — which the rain immediately washes down to the soil.

It appears, then, that all the essential materials for vegetation are furnished by the atmosphere, and are brought to the plant in the most available form ; that plants actually derive their nourishment from this source ; and it might be shown, that all the constituents of vegetables (excepting the small earthy portion, that many species can do without) have, at some period, belonged to the atmosphere. Hence, vegetables may not improperly be considered as *formed out of air*, or as *so much solidified atmosphere !* They represent an amount of matter which the force of organization has withdrawn from the air, and confined for a time to the surface.

If this be true, as it certainly is, we might hastily infer, that the soil merely serves as a *foothold* to plants ; and that any given vegetable does in fact obtain all its nourishment directly from the atmosphere. The too unguarded statement of so distinguished a chemist as Professor Liebig seems to tend to this conclusion, and has been thus understood ; partly, as we think, from some misapprehension of his real meaning. Indeed, this view would appear to be fully borne out by such facts and considerations as the following.

Vegetation must have had a beginning. Science and sacred history equally point to a time, when no vegetable matter existed in the soil which overspread the earth's surface. The first plants *must* have grown without the aid of either vegetable or animal matter ; they *must* have derived their whole organic food directly from the air. Nor are we left to speculations which go back to the origin of vegetation. This process is often repeated on a small scale, even in our own times ; as when small volcanic islands are raised from the sea, and the bare inorganic soil is gradually clothed, first, perhaps, with humble lichens, then with mosses, ferns, and rushes, and at last with common herbage, shrubs, and trees, — forming, in time, a vast accumulation of vegetable matter, where none at first existed. So, likewise, after an eruption of molten lava or volcanic ashes from Etna, heated so as to destroy every vestige of organic matter that we can imagine to have existed therein, the soil thus produced is often covered with rich vegetation in less than a century.

In all these cases, no vegetable matter has been conveyed to these perfectly sterile mineral soils, except the minute portion contained in the seeds, &c., wafted thither by winds or waves. And yet a vast quantity has been produced, and is represented not only by the existing vegetation, but by the rich mould imparted to the soil by the decay of previous generations. What is the source of this vegetable matter? The necessary materials exist in the air. Plants possess the peculiar faculty of drawing them from the air. The air must have furnished the whole.

We may submit this view to the test of actual experiment, by causing any common seed of known weight — a garden bean, for example — to germinate, as it readily will, on pounded flints, watered with rain-water alone. When the plant has attained the fullest development of which it is capable under such circumstances, it will be found to weigh many times as much as the seed from which it sprang. It may be supposed to derive a portion of its weight from the flinty soil. Let its ashes, therefore, be deducted, and its carbon alone taken into the account. This element, which may have increased perhaps fifty or a hundred fold, can have been derived only from the carbonic acid brought to the plant by the rain-water and the air.

Many striking confirmations of this fact fall under the notice of the agriculturist. He well knows, that, when an impoverished soil is laid down to grass, the longer it remains in undisturbed vegetation, the richer in vegetable mould does the soil become. In our forests, also, a vast amount of vegetable matter is accumulated in the trunks of the trees. Do they draw this from a stock in the soil? How is it, then, that the vegetable mould in the soil increases with the age of the forest? As a whole, they must draw from the air not only the carbon which their trunks contain, but an additional quantity, which they impart to the soil, in the annual fall of leaves, &c.*

This point may be more strikingly presented by directing our attention to the case of a single tree. Let us take, for example, one of those gigantic Oregon Pines, which were noticed in a recent number of this Review, † — that tree whose prostrate trunk Douglas found to be two hundred and fifty feet in length, and tapering regularly from a base of fifty-eight feet in circumference. The solid contents of this trunk we may estimate, in round numbers, at 17,000 cubic feet. The weight of its wood, when seasoned, supposing it to have the specific gravity of our White Pine, — which it somewhat resembles, — would be 714,000 pounds. Of this, four pounds in every thousand must be allowed for the *ashes*, — the mineral constituents which have certainly been derived from the earth (2856 lbs.) ; leaving for its proper organic materials 711,144 pounds.

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* These points are well stated by Professor Johnston, in his *Agricultural Chemistry*, Lect. IV., from which we have taken many of the foregoing illustrations.

† *North American Review*, Vol. LIX., p. 223.

Taken as mere dry pine wood, half of this amount is carbon, namely, 355,572 pounds. But this tree abounds in turpentine and resin, — substances which contain a much greater proportion of carbon. We allow, to make round numbers, 428 pounds for the excess of carbon in this form. Disregarding the other elements, then, this tree has accumulated 356,000 pounds, or 178 tons, of carbon or charcoal in its trunk. Whence has this large amount been derived? From the ground? A thousand years ago, when the seed germinated which has given rise to this giant tree, the soil of the limited space its roots occupy could not, certainly, have contained the millionth part of the carbon which is now stored up in its trunk. It *may* not have contained a particle; for the Pine will thrive upon a sandy, sterile soil ; and these very trees, says Douglas, were actually growing "in nearly pure sand." In any given year, this tree must have returned to the soil, by its falling leaves and cones, quite as much as it took from it. Was it furnished with carbon from the falling leaves or decaying trunks of neighbouring trees and plants? A portion, certainly, may have been so supplied, in any given case ; but this only removes the question a step further back. Besides, this tree stood in a forest of similar Pines, — many of them equally, and some still more gigantic and venerable, — all of which have been accumulating carbon for hundreds of years at the same rate. There can be but one answer to this question. The immense stock of carbon, not only of this tree, but of the whole forest, has been drawn from the air.

And in a similar manner we might show, that the whole amount of all the organic elements of all plants was originally derived from the air. But does it therefore follow, that each and every plant actually draws all its food directly from the air? In certain cases, undoubtedly. The *Epiphytes*, or Air-plants, having no connection with the soil, live necessarily and directly on the atmosphere. So do those plants which first vegetate on volcanic earth, bare rocks, naked walls, or in pure sand. But we must particularly remark, that only a comparatively small number of plants will grow, or continue to live, under such circumstances; and, especially, none of the vegetables useful as food for man, or the higher animals, will thus thrive and come to maturity.

We have also seen, that the plants which do grow in this manner, as well as the undisturbed forest and grass land, deposit vegetable mould, and thus gradually make a soil rich in organized matter. Is this vegetable mould useless, and so left to escape, by slow decomposition, into the air from which it has been so laboriously withdrawn? Certainly not. Nature does not thus waste her strength, or relinquish the advantages she has gained over inorganic nature. The races of plants that may thus grow at the entire expense of the air gradually form a soil of vegetable mould during their life, which they increase in their decay; and their successors live more healthfully upon the inheritance, being supported partly upon what they industriously take from the air, and partly upon the ancestral accumulation of vegetable mould. In this way, each successive generation may enrich the soil; for, although drawing perhaps a large part of its nourishment from this store, yet it annually returns a portion by its dead leaves; and when it dies, it bequeaths to the soil not only all that it took from it, but all that it drew from the air.

It is in this manner, especially, that the humble lichens, mosses, ferns, and other plants which short-sighted man terms useless, play an essential part in the economy of nature. They *can* live directly upon the air. Their minute seeds, quite invisible to the naked eye, and in number far surpassing man's power of computation, — light almost as the air itself, — are widely scattered by the winds over mountain and plain, and lodged upon every naked rock, or stagnant pool, or tract of barren sand, where all they need is moisture to excite and maintain their growth. Some, like the lichens, require even little of this. They attach themselves to dry rocks, or plains of lava, which are washed only by the occasional shower; and here they make the earliest inroads upon barrenness. Not only do the accumulated remains of successive generations fill the crevices with fertile mould, and the water, which it holds like a sponge, by its freezing and thawing, aids in the disintegration of the rock; but many of them create, from aërial elements, *oxalic acid*, a powerful solvent, which, as it is gradually set free, acts upon and excavates the stony surface to which the plant firmly adheres. Thus the dying lichen digs for itself in the solid rock a sepulchre, in which its dust may rest. Well did Linnæus, in his lively fancy, term the lichens *vernaculi*, or *bond-slaves*, chained, as it were, to the rocks which they labor to cover with soil for the benefit of others, though they derive from it no nourishment for themselves.

Next, certain tribes of mosses take possession of this scanty soil, and more rapidly increase its amount; while others, of aquatic habits, convert shallow pools into quaking bogs, and create in time vast accumulations of vegetable matter in the form of peat. These are truly *servi*, as Linnæus termed them; servants to the nobler plants which soon succeed them. For then come the ferns, (the *novaccolæ*, or colonists,) after lichens have furnished them a foothold upon the rock, or mosses given them one upon the spongy and unstable morass. And these are the precursors of grasses, rushes, and other plants of more immediate importance to man and the higher animals; but which never would come to perfection, if left, like their humble but indispensable predecessors, to draw an unaided subsistence directly from the inorganic world. It is thus that the bare earth is at length enabled to support the sturdy forest, or the rich field of waving grain.

While it is strictly true, therefore, that all the organic elements, or the food of plants, have been originally derived from the air, it is not true, that what is contained in any given plant, in any one crop we raise, is directly drawn from the atmosphere alone. "A plant grows partly at the expense of the vegetable matter in the soil accumulated by preceding vegetables, and partly at that of the air. When it reaches maturity, or when winter arrives, it dies; and of its decaying structure, a part is resolved into air, and returned to the atmosphere; a part remains, and is incorporated with the soil. If that which remains be greater than that which the growing plant derived from the soil, the vegetable mould in the soil increases ; if less, it will diminish." When vegetation is left to its natural course, there is ordinarily an accumulation. But in agriculture, the farmer removes his crop from the land ; and so takes away not only what the plants have received from the earth, but also what they have absorbed from the air ; and, consequently, he exhausts the land rapidly. Hence, he finds it necessary to follow the example of nature, and to restore to the soil, in the form of manure, an amount substantially equivalent to what he takes away ; in fact, to return to the soil every part of his crop that does not return to his pocket in the form of money.

To complete our view, we should now consider the earthy constituents of plants, which, although unessential to the general question, are very important in their agricultural relations. The principal conclusions of the chemical physiologists upon the subject seem to be these : first, that different vegetables take from the soil, or at least retain in their system, unequal proportions of earthy matter, — some more of one thing, some more of another ; and, secondly, that each species must obtain those earthy materials which form a constituent of its fruit, seed, &c. ; else it will not live a healthful life and come to maturity. We hasten to another part of our subject.

We have learned what the food of plants is, and whence they obtain it. Their universal food is rain-water, which has absorbed some carbonic acid, nitrogen, and ammonia or its compounds, from the air, or dissolved them from the decomposing remains of former vegetation already existing in the soil ; whence it has also dissolved a variable quantity of earthy matter. This liquid is imbibed by the roots, and carried upwards through the tissues of the stem. But it is still the raw material of growth, — crude sap, — mineral matter, — *of the earth, earthy*, — and as yet incapable of forming a part of the living structure. How does the plant turn it to account, and convert it into its own substance ?

For this purpose, the crude sap is carried into the leaves. The leaves and other green parts of plants (or, more strictly, the *chlorophylle*, or green matter they contain) constitute the apparatus of vegetable digestion. The agent, the motive power which puts this most curious chemical apparatus into action, is *solar light*. This is the indispensable agent by which lifeless mineral matter — earth and air — is transformed into the organized substance of living plants, and consequently of animals. Such is the important part which light performs in vegetable digestion ; that initial step in organized existence, upon which, as the first link in the chain, all the rest absolutely depends. Hence, the creative fiat, "Let there be light," was the immediate precursor, as it is the indispensable condition, of organized and animate existence.

Under the influence of light, this curious machinery is constructed, and the *chlorophylle* — the green matter of vegetation — is first developed. When plants vegetate in insufficient light, — as potatoes shoot in our cellars, — this green matter is not formed. When light is withdrawn, it is soon decomposed ; as when celery is blanched by heaping the soil around its stems. Under the influence of the solar rays, an essential preliminary step in vegetable digestion is accomplished ; namely, the concentration of the crude sap by the evaporation or exhalation from the leaves of the now superfluous water. This exhalation, its amount, its dependence upon sunshine, and its obvious consequences upon the rise of the sap, the early death of the leaf, and as explaining how the plant can draw sufficient nourishment from such excessively diluted food, we cannot here pause to consider. These are preparatory operations. We pass to the agency of light in that process in which the very essence of vegetation consists ; namely, its action, in the leaf, upon the concentrated sap. Here light accomplishes two perfectly unparalleled results, both of the highest conceivable importance in the economy of nature.

These are, first, *the chemical decomposition of one or more of the substances in the sap which contain oxygen gas, and the liberation of this oxygen at the ordinary temperature of the air*. In certain cases, the chemist, in his laboratory, can set free oxygen gas from its compounds ; but, for the most part, only with the aid of a heat equal to that of red-hot iron.

The second result has already been mentioned : *the actual conversion of this mineral, or inorganic, into organized matter*, — matter capable of forming, and which does form, the living tissue of all plants and animals.

These two great operations, though separately stated, to convey a clearer idea of the results, are carried on simultaneously, — are, in fact, but different aspects of one great operation. We contemplate the first, (the liberation of oxygen gas,) when we consider what the plant gives back to the air. We contemplate the second, when we inquire what the plant retains as the materials of its own growth. The concentrated sap is decomposed ; the portion which is not required in the plant's growth is returned to the air ; and at the same time, the remaining elements are rearranged so as to form new and peculiar products, — *organic* products. The principal material which is given up to the air, in this operation, is oxygen gas, that element of our atmosphere which alone renders it fit for the breathing and life of animals. That the foliage of plants in sunshine is continually yielding oxygen gas to the surrounding air has been familiarly known since the days of Senebier, Ingenhouz, and Priestley.

We shall not attempt to trace the history of this beautiful discovery, which any one may verify for himself, by exposing some freshly gathered leaves to the sunshine in an inverted glass vessel filled with water, so as to collect the bubbles of air which rise, and which, on examination, prove to be nearly pure oxygen gas. The evolution of this gas goes on while the sun shines, but immediately stops when a shadow is cast over the leaves, and is resumed when the screen is withdrawn, or when a gleam of reflected sunlight is cast upon the leaves from a mirror ; thus showing how entirely the whole depends upon sunshine. In nature's operations, diffused daylight answers the purpose ; but in our rude experiments, we cannot quite imitate the delicacy of her processes. What is the source of this oxygen gas, which is thus given out to the air just in proportion to the vigor of vegetation ?

To take the simplest and most general case, — suppose the plant is converting its inorganic food directly into the materials of its own growth, the very matter of which its fabric is constructed. This matter — the *lignin* of chemists, the material of wood and of the whole vegetable structure — is composed of carbon, oxygen, and hydrogen ; of which, the two latter exist in the same proportions as in the composition of water. As a convenient form of expression, it may therefore be said to consist of carbon and the elements of water. These materials are, of course, furnished by the food upon which the plant lives. But this universal, all-essential food, we have seen, is carbonic acid and water. If these elements be decomposed, as we know they are, by the solar rays, and the carbonic acid merely relinquish its oxygen, we have left carbon and water, or the elements of water, the very composition of vegetable tissue. It can scarcely be doubted, then, that the oxygen gas, which is in such case given up to the air, comes from the carbonic acid which, as we have shown, the plant took from the air.

There is a beautiful mode of testing the correctness of this view. Since the air-plants, to which we have so often alluded, must necessarily imbibe directly from the air into their leaves all the carbonic acid they consume, it would naturally be inferred, that common plants take in, or may be made to take in, a part of their carbonic acid in the same way. Accordingly, small leafy plants, or handfuls of fresh foliage, have been exposed to the sun in glass vessels, while a current of carbonic acid is made slowly and repeatedly to pass over them. The leaves seize the carbonic acid with avidity, and give back oxygen gas in its place. It is clear, therefore, that the oxygen which is given to the air, in ordinary vegetable digestion, comes from the decomposition of carbonic acid. Plants take this latter gas from the air, directly or indirectly; they retain its carbon; they restore to the air pure oxygen.

Next, let us suppose that the plant, instead of transforming its food immediately into new tissue, new branches and leaves, chooses to accumulate it for future use. In that case, it is first converted into gum or mucilage, and thus conveyed by the returning circulation to the place where the *depôt* is established, — perhaps in the root, like the turnip; or in subterranean portions of the stem, as in the potato; or even in the wood; and there stored up in the form of starch. Now, it is remarkable, — it is, indeed, one of the most interesting discoveries of the present age, — that both gum and starch, which plants so largely create for their own future consumption, have exactly the same chemical composition as vegetable tissue itself; a composition like that represented by carbon and the elements of water. In their formation, likewise, the carbonic acid of the sap yields all its oxygen to the air.

Sometimes the digested food is accumulated in the more soluble form of sugar, ready for rapid consumption in flowering; as in the stalk of the sugar-cane and maize, and the root of the beet. But sugar has the same chemical composition as starch and vegetable tissue, with the addition of another atom of water in the case of common or cane-sugar, and of three atoms in grape-sugar. Its formation, in all cases, gives the same amount of oxygen to the air. The conclusion becomes more and more evident, that, *by so much as plants grow*, they take carbonic acid from the air, retain its carbon, and restore its oxygen.

Since these general vegetable products are essentially identical in chemical composition, it is no longer such a special wonder, that they should be mutually convertible; that the plant, when it draws upon its accumulated stock, should so promptly change the form of the investment from starch into mucilage or sugar, or *vice versâ*, and finally into vegetable tissue. Even the chemist in his laboratory effects some of these transformations, though in one direction only. He can possibly change woody fibre into starch, and thus, as has been thought, make bread of wood; he can certainly change woody fibre into sugar, as well as starch into gum and into sugar. But he cannot reverse the spell, and convert sugar into starch, or either into wood, as the plant so readily does. And as to creating these or other organic products from their original elements, — carbonic acid and water, — that is the prerogative of the plant alone.

When the plant forms vegetable acids, a part only of the oxygen of the carbonic acid is restored to the air; when oils and resins are produced, which consist of carbon and hydrogen only, the oxygen of the water must also be evolved. In the formation of gluten, vegetable albumen, and all the important quaternary vegetable products, the nitrogen of the plant's food is an essential element; but oxygen gas is equally given to the atmosphere from the decomposition of carbonic acid.

As concerns the atmosphere, then, the principal result of vegetation appears to be the withdrawal of carbonic acid, and the restoration of its oxygen. This is the constant effect of vegetation, and the measure of its amount. It is probably true, indeed, that leaves decompose carbonic acid in the full light of day. There is no doubt, that, in the night, they sometimes give a quantity of carbonic acid to the air, or even rob it of a little oxygen. But this by no means affects the general result, or requires any qualification of our broad statement. The work ceases merely when light is withdrawn. But whenever the exhalation of water from the leaves slowly continues in darkness, the carbonic acid which this water holds in solution necessarily flies off with it, — escapes undecomposed, during the necessary interruption to vegetation, into the atmosphere from which the plant took it ; just as the alcohol evaporates from the wick of a spirit-lamp after the light is extinguished. So much of the crude sap, or raw material, merely runs to waste.

But further ; we must bear in mind, that the decomposition of carbonic acid by light, in the leaves, is in direct opposition to the ordinary laws of chemical affinity ; in other words, that all organized matter is in a state of unstable equilibrium. When light is withdrawn, therefore, what wonder if common chemical forces should resume their sway, — the oxygen of the air combine with some of the newly deposited carbon, and again form a little carbonic acid; thus demolishing some portion of the rising vegetable structure which the setting sun left in an unfinished and unstable state. This always does take place, when a plant is kept in prolonged darkness ; and in a dead herb, at all times, chemical forces exert their power uncontrolled, and pull down the whole vegetable fabric, beginning with the all-important green matter, — as we observe in the blanching of celery, — and at length resolve the whole tissue into the carbonic acid and water of which it was made. All this must be placed to the account of *decomposing*, not of *growing*, vegetation ; and, therefore, does not affect the general result, that, by so much as plants vegetate, they decompose carbonic acid and give its oxygen to the air; in other words, they purify the air.

We may not only show, that this contrary action of vegetation during the night is incidental, but we may deny its universal occurrence. In repeating the old experiments with due precautions, and with the advantage of improved means of research, one of the most acute analytical chemists of the age found, that the plants he employed, while in full health, gave no carbonic acid to the air during the night, and consumed no oxygen.* This anomaly, which has so long been taken for granted, and so greatly misunderstood, — having even been dignified with the name of the true respiration of plants, — has no existence as a general phenomenon. Plants deteriorate the air only in their decay, and in certain special operations to which we may presently allude.

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* Pepys, in Phil. Trans., 1843, p. 329.

Let us first obtain some general notion of the amount of the influence of vegetation, as such, upon the air we breathe. For every six pounds of carbon which plants have accumulated in their structure, they have withdrawn from the atmosphere twenty-two pounds of baleful carbonic acid gas, and replaced it with sixteen pounds — an equal bulk — of life-sustaining oxygen. Consider the quantity extant merely in the trunks of trees. The trunk of the single giant Pine already mentioned contains 356,000 pounds of carbon, — a quantity sufficient to propel on our railroads 200 tons of merchandise a distance of 3,560 miles! In its growth, this tree withdrew from the air 1,305,333 pounds of carbonic acid gas, and replaced it with 949,333 pounds of oxygen gas; a quantity sufficient to maintain the respiration of a single man for 1,110 years. It is, perhaps, worth noticing, that the age of this great tree has been somewhat roughly estimated at 1,100 years;* so that, year by year, it has supplied oxygen to the air just at the rate at which a single man would consume it. Add to the quantity of carbon gathered by this one tree all that is contained in the forests and herbage of the world, — all that has accumulated in the soil as vegetable mould, peat, and in other forms, — all that is locked up in the vast deposits of coal, the product of the vegetation of by-gone ages, — and, finally, let the estimate embrace all that belongs to the bodies of the whole existing animal kingdom, — and we shall have the expression, if it can be made in figures, of the amount of a single, though the largest, element which vegetation has withdrawn from the atmosphere. If we multiply the vast amount of carbon by sixteen, and divide it by six, we obtain the number of pounds of oxygen gas that have, in this process, been supplied to the atmosphere. An immense operation, therefore, on a scale commensurate with the grandeur of nature, is in progress, and has been going on ever since the world began. *What is its object?*

To answer this question, consider, first, that vegetation is, so far as we know, the only operation in nature which gives to the air free oxygen gas, that indispensable requisite to animal life. All prevailing chemical tendencies, on the contrary, take oxygen *from* the air. The materials of the earth's crust are not all saturated with it; many of them still rob the air of oxygen by all the changes they naturally undergo; and none of them, by any known natural process, give back a particle in the useful state in which they took it, — uncombined, or in a condition to support animal life. Animals all consume it, at every moment of their life, giving to the air carbonic acid in its place; and, when dead, their decaying bodies consume still more.

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* *N. A. Review*, Vol. LIX., p. 226.

Decomposing vegetable matter tends to the same result. Its carbon, taking oxygen from the air, is restored in the form of carbonic acid. Combustion, as in the burning of fuel, amounts to precisely the same thing. It is merely rapid decay. The gigantic Pine, from which we have so frequently drawn our illustrations, has, for the last thousand years, been slowly gathering its carbon from the air. If the prostrate trunk be left to itself, it may be almost as slowly restored to the air in the original form of carbonic acid. But if set on fire, the whole work may be done, or rather undone, in a day.

All these great causes conspire to rob the air of its life-sustaining oxygen. The original supply is, indeed, so great, that, were there no natural compensation, centuries upon centuries would elapse before the amount of oxygen could be so much reduced, or that of carbonic acid increased, as sensibly to affect the present races of animals. Such a period, however, would eventually arrive, were there no provision for the decomposition of the carbonic acid, and the restoration of its oxygen. We have seen, that vegetation accomplishes this very result. The needful compensation, therefore, is found in the vegetable kingdom.

While animals consume the oxygen of the air, and give back carbonic acid, which is injurious to their life, this same carbonic acid is the principal element of the food of vegetables, — is consumed by them, and the oxygen restored for the use of animals. Hence, the necessity of the vegetable kingdom in purifying the air we breathe. Hence, the perfect adaptation of the two great classes of living beings to each other; each removing from the atmosphere what would be noxious to the other, — each yielding to the atmosphere what is essential to the continued existence of the other.

And yet, in one point of view, this reciprocity, as Sir Boyle Roche would say, is nearly all on one side. The vegetable kingdom not only preceded the animal, but might have continued to exist alone, though, perhaps, not in its present extent and variety. The decaying races of plants, yielding their carbon to the soil and to the air, would furnish food for their successors. Let it be remembered, that the whole carbon of the carbonic acid, which animals render to the air in breathing, they have drawn from the vegetable kingdom in their food. In time, it would all have found its way back to the air, ready for new generations of plants, without the intervention of animals. At most, they merely expedite its return. It is quite as probable that they retard it. Not so with animals. No act of theirs, no natural process besides vegetation, restores the oxygen they consume to the atmosphere. The service which the vegetable kingdom renders to the animal, in this respect, therefore, though remotely, is yet really, essential to their continued existence.

But this is only one aspect. The vegetable kingdom renders to the animal another service, so essential, that its failure for a single year would depopulate the earth ; we refer to the indispensable agency of vegetables in providing the food of the whole animal kingdom. Annihilate plants, and the greater part of the animal races — all the herbivorous animals — would immediately die of famine ; the carnivorous would soon perish ; their bodies ere long would be resolved into their original air and dust, and nothing but the bare mineral kingdom, or lifeless, unorganized matter, would remain. We need not repeat the now familiar statement, that plants are the great, the sole, producers of organic matter. This is their grand office. They alone convert the materials furnished chiefly by the atmosphere ; they *condense air* into organized matter. While plants thus produce upon such a vast scale, they consume or destroy comparatively little. Even when they do consume their own products, it is not in the mere vegetation ; but in the accomplishment of some special results, chiefly in flowering. They often seem to *consume*, when they only *transform* and *transfer*. When they apparently consume the nutritive matter accumulated in the root of the carrot, for instance, or in the tuber of a potato, they in fact transform it, for the most part, into branches, foliage, and flowers.

Animals *consume* what vegetables *produce*. They themselves produce nothing; they can produce nothing directly from the mineral world; they are only consumers. The herbivorous animals take from vegetables the organized matter which these have produced; a part of it they consume, — in respiration chiefly, — restoring the materials to the atmosphere, from which plants derived them; in the very form, too, in which they were originally taken, namely, as carbonic acid and water; which is what all animals render to the air in breathing. Some of the carbon, as well as all the nitrogen, is restored to the air in other forms. That which herbivorous animals do not thus restore they accumulate in their tissues. This constitutes the food of carnivorous animals, who consume and return to the air the greater part during their life, and the remainder in decay, after death. This accomplishes the revolution. The atmosphere, out of which plants create nourishment, and to which animals, as they consume, return it, thus connects the animal and vegetable kingdoms, and completes the great cycle of organic existence. Organized nourishing matter passes through various stages in vegetables, is raised to a higher life in the herbivorous animals, and undergoes its ultimate transformations in carnivorous animals. Portions are lost (consumed) at every stage; and, dropping out of the ascending current, fall back to the mineral state; to which the whole, having completed the round, finally returns.

We may here incidentally notice a beautiful subsidiary arrangement in this great system, which has quite lately been happily explained by the English Cuvier, Professor Owen. In our broad view, we suppose the dead and decaying tissues, both of animals and vegetables, to be resolved entirely into inorganic matter before they again enter the ascending current of organization; and this, no doubt, is generally the case. But here an important auxiliary part — a labor-saving operation — is performed by the animalcules, or infusory animals. When we consider their almost incredible numbers, — their fossil remains, even, forming vast deposits in many parts of the world, — their universal distribution, their astonishingly rapid multiplication, their insatiable voracity, and that they devour and assimilate the particles of decomposing vegetable and animal bodies, in their downward career just about to escape from the organic system; we cannot doubt that they play some important part in the economy of nature, — nor long fail to perceive what that part is. Although they create no organized matter, yet they prevent the gradual diminution of that which already exists. For, as Professor Owen remarks,

> "When organized matter is dissolved or suspended in water (as in any vegetable infusion, in the washings of the soil collected in pools, and streams, &c.) in that state of comminution and decay which immediately precedes its final decomposition into the elementary gases, and its consequent return from the organic to the inorganic world, the minute infusory animals, these wakeful members of nature's invisible police, are everywhere ready to arrest the fugitive organized particles, and turn them back into the ascending stream of animal life. Having converted such particles into their own living tissues, these animalcules become themselves the food of larger infusoria, and of numerous other small animals; which are, in turn, devoured by larger animals, such as fishes; and thus a *pabulum*, fit for the nourishment of the highest organized beings, is brought back, by a short route, from the extremity of the realms of organic matter." *

This is not the only instance in which the feeblest and apparently most insignificant instruments, such as animalcules wholly invisible to the naked eye, are made, by their immense multiplication, or by their continued agency through long periods of time, to accomplish the most important results. Mr. Owen's suggestion is the more interesting from its furnishing such a complete explanation of the vegetable source of the food of the countless tribes of aquatic and marine animals, thus removing the only difficulty that stood in the way of these generalizations. When we consider what an incalculable quantity of organized matter, dissolved or washed away by rain, is carried into our streams and rivers, and thence into the bosom of the all-absorbing ocean, we might be led to speculate upon the vast waste of material consequent upon the working even of this admirable terrestrial system. But the myriads of beings that animate the deep are nature's witnesses that she allows no such waste.

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* *Lectures on the Comparative Anatomy and Physiology of the Invertebrate Animals.*

When the farmers along our sterile coast manure their exhausted lands with fish, they merely reclaim their own, and bring back to the soil what has been washed into the sea.

But returning from this slight digression to the main topic, we must not omit to notice one of the most interesting, as it is one of the most recent, conclusions of chemico-physiological science ; which carries out the leading idea, that the plant is an apparatus of production, to the fullest extent. It is now, perhaps, substantially proved, that plants not only furnish all the elements of the animal structure, but furnish each principal material ready-formed. Each constituent of the animal frame is prepared beforehand by the vegetable. The animal has only to appropriate it.

For example, the fat of an herbivorous animal is directly drawn from the oil and waxy matters which his vegetable food contains, and which pass, without essential chemical change, into the state of fat in the animal structure ; there to be consumed, *burned*, indeed, in respiration, and so resolved into carbonic acid and water, just as it would have been if burned in our lamps. The fibrin, which constitutes the muscles or flesh of the animal, and much of the solid portion of his blood ; the gelatine, of which the sinews and the organic part of the bones consist ; and the casein, which forms the curd of cheese, — these are essentially the same as the gluten of flour, the legumine of beans; and they exist ready-formed in the seeds and herbage of the grass on which the animal feeds. Many plants, indeed, produce actual fibrin ; it is a large ingredient of the milk of the famous *Palo de Vaca*, or Cow-tree of Caraccas, which contains all the constituents of that most important animal product ; — a tree which serves as a substitute for kine to the whole neighbourhood. The earthy portion of his bones, and the iron in his blood, are equally drawn, ready-formed, from the earthy constituents of the vegetables upon which he feeds. The animal merely accumulates these materials, changing them, it may be, little by little, as he destroys them, but giving them all back finally to the earth and air. Literally, then, "all flesh is grass." The wants of the animal kingdom were all prospectively provided for, when to them was "given every green herb for meat."

Let us take a final glance at the general economy of organic nature, in its relations to man. Under this aspect, man is an interpolation. The whole system is perfect without him. It is independent of man, and might have gone on — as geologists assure us it did go on — for ages before his introduction upon the stage. But when man was at length introduced into this his temporary residence, and to him was "given dominion over" the organic world, he found a system in operation, every part of which he could turn to good account. The various influences of man upon the vegetable creation, and their consequences, form a subject much too wide and fruitful for present consideration. We barely advert to his relations to vegetation considered merely as furnishing nourishment.

Every other portion of creation, every species of plant or animal, stands in some particular part of the series, in more or less explicit relation to certain tribes upon which it feeds, and to certain others by which it is consumed. But omnivorous man steps in at each and every stage through which organic matter, or food, passes. Sometimes, interrupting the series at the initial step, he consumes the green and tender herb, or the foliage, — the very instrument for creating food. To subsist in this way, however, requires almost uninterrupted feeding. Possibly, men could thus subsist in the warmer climates; but a small number of them would require a large extent of territory, and even the lowest form of civilization would be unknown. Man, therefore, waits for the next step in vegetation; he allows the leaves to perform their office; and when they have accumulated a store of more concentrated nourishment in the root, as in the turnip, or in subterranean stems, as in the potato, or even in the leaves themselves, as in the cabbage, he seizes the deposit as his own.

For a larger part of his food he is content to wait still longer. He allows the plant to flower, and itself to use the accumulated store, and to deposit a large part of it anew in the fruit, and especially in the seed or grain; which furnishes to man his food in higher concentration than any other vegetable production. Grain, therefore, by affording leisure, is the parent of civilization. In the cereal grains we have the highest result of the vegetable kingdom, considered as furnishing nourishment. Nature's most beneficent gifts to man are wheat, rice, and maize; of which the two former were given, one to the cooler, the other to the hotter portions of the Old World; while the third was presented to the New. It is not surprising, therefore, that the *cerealia* have from the earliest times been regarded with a kind of religious reverence in every part of the world. The grain, indeed, contains no peculiar product, nothing that does not also exist in the herbage ; it only contains these elements in the most concentrated form. A grain of maize or Indian corn — one of our own great staples, and the father of that ruder and imperfect civilization which preceded ours in the warmer parts of this continent — may serve to illustrate the manner in which each essential element of food is condensed in all the *cerealia*. The greater part of its bulk consists of starch, with other isomeric products, here accumulated for the early support of the enclosed embryo plant, when it struggles into life in germination ; but which, when it becomes the farinaceous food of man and other animals, is in respiration resolved into its inorganic elements, with the evolution of heat. The outer portion of this farinaceous mass, as well as the embryo plant itself, is soaked in oil ; the source of the fat in the animals which consume it. Throughout the whole is diffused the nitrogenized class of products, such as gluten, vegetable albumen, &c., which in the animal economy are turned at once into the fibrin of flesh or muscle, the gelatine of the bones and sinews. And, finally, in that part of the seed chiefly which belongs to the embryo plant itself — as Dr. Hayes and Dr. C. T. Jackson have shown — certain mineral ingredients are stored, such as the phosphates of lime and magnesia, which form the earthy part of the bones of animals, and the iron which performs an important function in the blood.

But man has still another resource, — one which he might possibly dispense with in tropical climes ; though it is indispensable, if he would colonize the cooler parts of the world. To obtain his food in a still more concentrated form, he is obliged to call in the aid of his fellow-consumers in the animal kingdom. He makes the domestic animals graze for him, — an employment for which their ample stomachs and abundant leisure are well adapted ; he even supplies them with esculent roots, fruits, and grain ; and, in their flesh, he receives again his universal food, changed only in form, and in the greatest possible degree of concentration.

The question has often been warmly discussed, whether man is naturally herbivorous or carnivorous. But as his nourishment is essentially the same from whatever source derived, the question resolves itself into others, respecting the degree of concentration in which it is desirable he should receive his food, the very important effects of variety in diet, and whether it be intended that man should colonize the colder parts of the earth. Vegetable food may suffice within the tropics, and perhaps for warmly clad and inactive people in the temperate zones. To learn whether the natives of the colder parts of the world are intended to subsist directly upon vegetable food, we have only to compare the meagre crops of grain or of esculent roots, that can be raised north of fifty-five degrees of latitude, with the actual amount of food required to support life and health in the colder regions. For example ; in the last exploring journey to the shores of the Arctic Sea, — that of Simpson and Dease, — the daily ration of each man, when the supply allowed was from *eight to twelve pounds of venison !* And the agent of the North American Fur Company states, that the men employed in active service, when restricted to this aliment, consume some eight pounds of fresh meat a day, or ten pounds when the bones are included.

To whom is science indebted for the fine generalizations, some of which we have been attempting to exhibit, and for the discoveries upon which they are based ? Our remarks have already extended so far, that little space remains for answering this inquiry. But we may say, with Dumas, that the fruitful series of discovery commenced with Lavoisier, the father of modern chemistry. That Lavoisier clearly apprehended the all-essential influence of light to organic life will appear from the following sentence, which, for convenience, we cite from the translation of the Discourse of Dumas. " Organization, sensation, voluntary motion, life, only exist on the surface of the earth, and in places exposed to light. It might be said, indeed, that the fable of Prometheus was the expression of a philosophical truth, which had not escaped the penetration of the ancients. Without light, nature were without life and without soul ; a beneficent God, in shedding light over creation, strewed the surface of the earth with organization, with sensation, and with thought." To Lavoisier must also be attributed the discovery of the true theory of respiration and animal heat. Respiration, he distinctly announced in the last volume of his Memoirs, is nothing more than a slow combustion of carbon and hydrogen, resembling that which takes place in a lamp; the atmosphere, as in all other cases, furnishing the oxygen, while the body and blood of the animal, which *burns* and *consumes*, supply the combustible matter; and the heat thus evolved maintains his elevated temperature. Hence, did not animals habitually replenish, by their food, the loss they constantly sustain in respiration, they would shortly die, as a lamp goes out when its oil is consumed. The torch of life is lighted when the child begins to breathe, is kept burning by the constant supply of aliment, and is finally extinguished in death. The obvious objection, that the lungs — the furnace where this combustion was supposed to be going on — should be warmer than the remote parts of the body, which is not the case, was long ago disposed of by the modified view of Lagrange, Vogel, Home, and Brande, and by the more recent confirmatory experiments of Bischoff and Magnus; which go to show, that the combustion takes place, not in the lungs, but in every part of the body to which the oxygen that supports it, absorbed in the lungs, is conveyed by the arterial circulation. Even the office of the red particles of the blood, as carriers of oxygen, of late so strikingly set forth by Liebig, was long since suggested by Sir Humphrey Davy.

We owe to Senebier the discovery of the opposite action of vegetables upon the air; namely, the decomposition of carbonic acid in the green parts of plants under the agency of the solar rays, and the evolution of its oxygen. But to Adolphe Brongniart belongs the credit of having, nearly twenty years ago, assigned the carbonic acid of the atmosphere as the source of all the carbon of plants, and consequently of animals. He developed this idea in the form of some very interesting geological speculations respecting the constitution of the atmosphere, and the state of organized existence in the earliest times. If all the carbon of existing plants and animals and their remains, as well as that which, gathered by vast primeval forests, is now buried in the bosom of the earth in the form of coal, — and, we may add, that in coral and in all the lime-rock to which marine animals have given rise, — if this immense quantity of carbon, previous to the creation of organized beings, was diffused through the air in the form of carbonic acid, it would follow, that our atmosphere, which now contains less than a thousandth part in volume of this gas, must then have contained a much larger proportion ; a proportion so large, probably, as to inhibit the existence of warm-blooded terrestrial animals. And accordingly, at the epoch of the coal formations, when vegetation must have had an extraordinary luxuriance, not a single terrestrial air-breathing animal appears to have existed. But when this ancient vegetation had withdrawn a large amount of carbonic acid from the air, and replaced it with an equal bulk of oxygen, a variety of air-breathing reptiles of monstrous size and form made their appearance ; animals which, from the nature of their respiration, are capable of living in much less pure air than is requisite for those of higher organization, of which they were the heralds and precursors. For it was not until after these vast stores of carbon had been abstracted from the air, and the retiring ocean and other causes allowed a larger portion of the earth's surface to be clothed with verdure, that a number of mammiferous animals, analogous to those now existing in the world, seem to have appeared upon its surface. At present, it is not probable that vegetation, in its *ensemble*, is accumulating carbon upon the earth's surface, and consequently increasing the proportion of oxygen in the air, to any considerable extent. The organic and inorganic forces must be nearly in equilibrium. By so much as vegetation tends to increase the proportion of oxygen, it also tends to increase both the energy of respiration in animals and the rapidity of the decomposition (oxygenation) of vegetable and animal remains, and the consequent restoration of the carbonic acid to the atmosphere, whence it was drawn. The agency of vegetation, having brought the air to that degree of purity which comports with the active respiration of warm-blooded animals, while, at the same time, it affords sufficient *pabulum* for plants, the opposing influences of these two orders of beings conspire to maintain the air in a state of stability.

May we not carry our speculations into the former constitution of the atmosphere a step further back ? May we not contemplate the physiological agency of vegetation, so early and largely introduced, as repairing the effects of an earlier physical operation, which must have greatly altered, in an opposite mode, the original constitution of the air ?

As the earth's crust cooled down from the state of incandescence upon which geologists love to speculate, incalculable quantities of free oxygen must have been withdrawn from the air, and imprisoned in the oxydation of its mineral elements, with a force which no subsequent natural agency, at any rate upon a large scale, has been able to loosen. The vegetation which supervened, stimulated to high luxuriance by the fine *bottom heat* and reeking atmosphere of those times, began to repair this loss, by decomposing the carbonic acid of the air, and thus increasing the relative amount of its oxygen. Thus the beds of iron ore and of coal, which accompany and overlie each other upon the earth's rind, have withdrawn from the original atmosphere, the one a portion of its oxygen, the other a portion of its carbonic acid. When we would obtain the former in its primitive and useful state, we mingle the ore with the coal, and drive off the oxygen, surcharged with carbon, again into the air from which both originally came, by the aid of the heat which the vegetables that gathered the carbon had absorbed from the sun's rays.

This idea, that plants absorb light and heat — a true force — from the sun, as well as that they constitute a deoxydizing apparatus, reducing the oxydized products of animal life, is claimed by Dumas and Boussingault. The latter promulgated the opinion, that plants absorb light or caloric, in the year 1837. And Dumas sets forth the following *programme*, as exhibiting the doctrines of his discourse.

AN ANIMAL IS	A VEGETABLE IS
An apparatus of combustion.	An apparatus of reduction.
Possesses the faculty of locomotion.	Is fixed.
Burns carbon,	Reduces carbon,
hydrogen,	hydrogen,
ammonium.	ammonium.
Exhales carbonic acid,	Fixes carbonic acid,
water,	water,
oxide of ammonium,	oxide of ammonium,
azote or nitrogen.	azote or nitrogen.
Consumes oxygen,	Produces oxygen,
neutral azotized matters,	neutral azotized matters,
fatty materials,	fatty materials,
starch, sugar, gum, &c.	starch, sugar, gum, &c.

Produces heat,	Absorbs heat.
electricity.	Abstracts electricity.
Restores its elements to the air or to the earth.	Derives its elements from the air or the earth.
Transforms organized into mineral matters.	Transforms mineral into organized matters.

That plants decompose water as well as carbonic acid, at least in certain operations, and liberate its oxygen, has recently been demonstrated by Boussingault. That vegetable tissue has the same identical composition as starch and other ternary organic products was first clearly proved by Payen. The mode in which these products are consumed and restored to the air by animals was popularly taught from about the same period (as early as 1839) by Liebig and the French chemists. The discovery of the part which ammonia plays in vegetation, as *one* principal source of the plant's azotized food, (for Liebig's statement, that it is the sole source of the nitrogen of plants, was too hasty,) is claimed for M. Schattenmann. The essential identity of vegetable albumen with animal albumen, and consequently the general identity of the quaternary azotized neutral products of plants and animals, was first shown by Mulder ; who deduced the important consequence, "that the great mass of animal substances is supplied by the vegetable kingdom." The discovery of fibrin, as such, — the very material of the flesh of animals, — in the juices and fruits of certain esculent plants, was long ago made by Vauquelin ; its presence in wheat-flour has recently been ascertained by Dumas.

That the fat of herbivorous animals is directly drawn, like their other constituents, ready-formed, from their vegetable food, has been strenuously taught by Dumas, Boussingault, and Payen, and is amply confirmed, as to the general fact, by a variety of experiments and direct observations, which our limits forbid us to notice. Professor Liebig maintains, on the contrary, as our readers are well aware, that the fat of animals is produced by a transformation of the starch, sugar, &c., of their food. During the last year or two, a very piquant discussion upon this subject has been carried on between the Giessen and the Parisian chemists ; which has ended in the confirmation of an old observation of Hubert, that bees have the power of producing wax when fed upon sugar alone ; whence it follows, that ordinary herbivorous animals *may* produce fat from similar materials. But on the other hand, the French chemists have pretty clearly made out, that the fat of animals ordinarily comes directly from the oil and wax of their herbivorous food.

Another interesting question remains, which we have reserved to the last, because it is one which has particularly occupied the attention of Professor Draper, and forms the *gist* of his elaborate volume "on the forces which produce the organization of plants." The sunbeams contain light, and heat, and chemical, or, as Dr. Draper would say, *tithonic* rays. Which of these are the efficient agents in vegetable digestion? Which, in other words, enable the green foliage to reduce carbonic acid, and create organic matter? The old experiments of Senebier, the discoverer of this agency of light in vegetable digestion, as well as some recent researches of Mr. Hunt in England, seemed to show, that the violet and blue rays are most efficient; from which it was inferred, — as, indeed, would *a priori* be supposed, — that it is the chemical rays of the sunbeam which exert this wonderful power. This has ever been the prevailing opinion, and is taken for granted by Dumas. Observing that when he attempted to depict foliage by the *daguerrotype*, the green parts were not represented, Dumas remarks, that "it is as if the whole of the chemical rays essential to the photographic phenomenon had disappeared, had been absorbed and retained by the leaf. It would seem, therefore, that the chemical rays of light vanish entirely in the green parts of the plants; an extraordinary absorption, but easily explicable, when the enormous expenditure of chemical force necessary to decompose so stable a substance as carbonic acid is considered."

On the other hand, the experiments instituted some years ago by Professor Morren in Belgium, and Professor Daubeny in England, led them to the conclusion, that the yellow or most luminous rays, or, in other words, that light, strictly so called, was the efficient agent. Their experiments were made by exposing plants to sunlight transmitted through colored glass; a mode liable to obvious objections. To Dr. Draper belongs the credit of having devised and practised a much better mode of performing the experiment, namely, by exposing foliage in the solar spectrum itself to the influence of the different colors, and measuring the activity of vegetable digestion, or the amount of carbonic acid decomposed, by the quantity of oxygen gas evolved. And to eliminate the heat and chemical rays, he also employed those colored media which absorb in their passage the greater portion of these constituents of the sunbeam. The results he obtained confirm those of Morren and Daubeny, namely, that yellow or *luminous light* is the agent in vegetable digestion. They may, perhaps, be considered decisive on this point; for Mr. Hunt's experiments relate rather to the influence of light upon germination and the development of the green color, than directly upon the formation of vegetable tissue.

In whatever way this question may be settled, it advances us but a short distance towards the solution of the great problem, "*how* light acts in producing organization," to which Dr. Draper's volume is professedly devoted. But the whole that it really contains on the subject — all that it contributes to our former stock of knowledge or opinion — is embraced in the following hypothesis, which, so far as we know, has the merit of entire originality.

> "The very remarkable qualities which certain nitrogenized substances are known to exhibit, acting as ferments as they are undergoing decay, might lead to the supposition, that the decomposition of carbonic acid by leaves is due to the action of some nitrogenized body, the eremacausis of which is promoted by the rays of the sun." — p. 182.

And again,

> "There are many facts which go to prove, that the decomposition of carbonic acid is a secondary result, brought about by the action of nitrogenized ferment in a state of eremacausis, the sunlight operating in the first instance upon the ferment itself." — p. 183.

These facts, however, all resolve themselves into one, namely, the evolution of a quantity of nitrogen by leaves; which has long been known, but which has always been supposed to arise from the mechanical escape of a portion of the free nitrogen gas, necessarily absorbed, as we have seen, with the water which the roots imbibe. But Dr. Draper endeavours to show, that the quantity exhaled is much too large for such origin; and the results of his experiments (paragraphs 812 – 818) are certainly not only extraordinary in themselves, but in more than one respect apparently irreconcilable with those of Boussingault. "Its true source," he concludes, "is only to be sought in some nitrogenized compound present in the leaf, which is undergoing decomposition in some regulated way"; and upon this ferment he supposes that the light acts, to incite the decomposition of carbonic acid in vegetable digestion.

Surely, a bold theory is here built upon a very narrow, not to say an unsubstantial, basis; and when constructed, it helps us very little in the way of explanation. With due deference, therefore, we must still continue to believe, that the essential phenomenon of vegetable growth is something very different from the working of beer. No hypothesis could well involve a higher intrinsic improbability. It consists of Liebig's doctrine of fermentation, misapplied, as we think, to a case of a radically different order. Fermentation, germination, &c., are destructive processes; vegetable digestion is a creative process. In the former, vegetable tissue and vegetable products are *decomposed* and carbonic acid *formed*; in the latter, on the contrary, carbonic acid is *decomposed* and vegetable tissue and products are *formed*. Is it probable, that two such diametrically opposite processes as the formation and the destruction of organic matter are owing to the same or similar causes? that the gluten or albumen, which in the germinating grain of wheat incites the decomposition of vegetable tissue, starch, and sugar, and their resolution into carbonic acid and water, should in the leaf give rise to exactly the reverse effects, — the decomposition of carbonic acid and water, and the production of vegetable tissue, starch, and sugar? Besides, the formation of the nitrogenized products themselves is one of the essential results of vegetable digestion. Can their formation, then, be due to a process which in the first place involves their destruction? We will only add, that this hypothesis is open to another, by no means uncommon, objection; that of leaving the matter to be explained less plain than before. Framed purposely to explain the action of light on the foliage, it renders the phenomenon more obscure than ever, by gratuitously connecting it with a process (that of fermentation) which goes on quite as well in the dark.

We have taken special notice of this point, because it is the only one in the chemico-physiological portion of Professor Draper's volume, excepting the experiments upon vegetable digestion with the solar spectrum, that strikes us as new, — and with the purely physical part we are not disposed to meddle. We must except, however, the annunciation of the discovery, that "*the rays of the sun are the true nervous principle of plants!*" (pp. 102, 206, etc.,) an idea which is seriously maintained in a full and eminently verbose chapter. Thus this obscure subject is rendered as clear as daylight. Some modern physiologists have been vainly searching for the traces of a nervous system in the plant itself. They should have looked to the sunshine; unless, indeed, moonshine would do as well. Noteworthy, also, is the intimation, that our Indian summer — long a puzzle to philosophers — is owing to the heat evolved by the decaying foliage of the season! p. 93.

Dutrochet's explanation of the rise and circulation of the sap in plants by what he called *endosmosis*, and the reduction of this latter power to the general laws of capillarity and interdiffusion by Professor Graham and others, leave no novelty in Dr. Draper's very detailed chapter upon that subject; except in the proposition, — the truth of which we must still be permitted to doubt, — that the exhalation of the sap in the leaves exerts no essential influence upon its rise in the stem.

Chemists are naturally prone to magnify their office, and to explain almost every thing in the animal and vegetable economy upon chemical principles. In their views, frequently, the vital force — the organizing principle that animates the living body and controls its formation — plays nearly the same subordinate part as the Supreme Being in the system of the Brahmins. The latter admit the existence of a supreme deity, but suppose that he remains in a state of holy obscurity and inertness. The chemists kindly allow, that there may be such a thing as a vital force in the abstract, but are too apt to consider it a superfluity. At least, they would leave it nothing to do. But Dr. Draper is more hardy, and denies its existence altogether.

> "In this work, the existence of the vital force of physiologists — as a homogeneous and separate force — is uniformly denied. Living structures, far from being the product of one such homogeneous power, are rather the resultants of the action of a multitude of natural forces. Gravity, cohesion, elasticity, the agency of the imponderables, and all other powers which

operate both on masses and atoms, are called into action, and hence it is, that the very evolution of a living form depends on the condition, that all these various agents conspire. There is no mystery in animated beings, which time will not at last reveal." — p. 2.

Not only are living beings the result of the action or equilibrium of a great variety of common purely physical forces, — if we rightly apprehend the statement, — but the living body offers no more or other resistance to these physical forces than a dead carcass. For "it is a vulgar error," says our author, "that a living being possesses a principle of resistance to external agents, while a dead one submits to them ; both equally change, or, of the two, the living one putrefies and changes the more rapidly." (p. 6.) "Life and vitality figure away in these visionary speculations [the theories of physiologists] as though they were realities." (p. 41.) If, indeed, vital, as distinguished from common physical, forces have no existence, we may as well admit the doctrine with which the following sentence concludes. "What, then, are the final impressions left upon our minds by these general considerations ? They teach us, that life never occurs except in regions to which the imponderable agents can have access, an observation which is equally true of vegetable and of animal forms ; *that elementary organization directly or indirectly arises from the plastic agency of those all-pervading forces.*" (p. 14.) Surely, the author would disclaim the inference which he here seems to invite.

The scientific readers of Dr. Draper's large volume will find themselves as much mistaken as we were, if they suppose, that, although addressed to chemical philosophers, it is actually filled with original contributions to science. These, if separately presented, would occupy but a moderate space. Indeed, from the discursive and tropically luxuriant style, and from the particularity with which the author enters upon the most detailed explanations of perfectly trite and elementary matters, we should imagine that the treatise may have been originally prepared, and have done service, in the form of popular lectures to medical students. The introductory chapter, in particular, though well enough adapted for that purpose, an ill-natured critic might compare to an *omelette soufflée*, of which Dumas and Cuvier may have furnished the egg, Humboldt, Lyell, and others, the condiment, and Dr. Draper the intumescence.

The author's ingenious views on the rise of the sap in plants, and the circulation in animals, are prefaced by an elementary treatise on capillary attraction. Before we reach his proper observations on the action of light upon foliage, we have two very diffuse chapters to undergo, on the solar spectrum in general, Newton's theory of colors, the calorific and the chemical rays, and a great variety of elementary matters, with which a philosopher of the lowest acquirements might be presumed familiar, or for which, if he would refresh his school-boy recollections, he might turn to his forgotten text-books. And when at length the interesting experiment comes to be described, (the substance of which we have given in a former page,) the reader's attention is directed, not so much to the point which it was intended to prove, as to the gaudy tints that are reflected by the apparatus upon the wall of the room.

> "This prismatic experiment is one of the most beautiful objects which organic chemistry can offer, carried on in a chamber which would be totally dark, were it not for the intensely colored curves which are cast upon the walls by reflection from the tubes, — curves which often are many yards in length, indicating by their gaudy tints and brilliancy the intensity of the sun's light. The tubes and the vegetable leaves glow with the colors in which they are immersed. Meantime the most interesting phenomenon which can be witnessed is silently going forward; dead and inanimate matter is, under the influence of the plastic beam, putting on the form of organization and life." — p. 64.

This reminds us of one of the newspaper articles, emanating from an American observatory, upon the great comet of 1843, about the time of its first appearance. The observer, unfortunately, did not see the comet for which he was searching; but he filled his page with a glowing account of the twilight, and with some miscellaneous observations on the fixed stars.

And, finally, when the nervous principle of plants is considered, — and what that is our readers are already informed, — we are treated, by way of introduction, with a particular account of *the five senses;* of which the following may serve as a specimen.

> "The optic nerve, which gathers on its retinal expansion the images of outward forms, transmits them to the brain. To that cerebral tract to which it goes, the power is given to be affected by luminous agency; it is immaterial whether that agency consists of undulations of an ethereal medium, or spends itself in producing a chemical change of the retina. The *portio mollis* of the seventh pair, also, exposes itself in the cochlea of the ear, and having the function of audition committed to it, vibrates correspondingly to those oscillatory movements which constitute sound. So, too, with the olfactory nerve, which, pushing its way through the cribiform plate of the ethmoid bone, expands in a million of ramified branches on the Schneiderian membrane, and is ready to be impressed by odors or smells. There is no such thing as a mutual convertibility of the offices of these different machines; no vicarious interchange of action; each one has its own duty to perform, each has to discharge its proper task, and the construction of each is suitably arranged. In human contrivances, the same necessity of result arises; the telescope will not answer for a piano, nor a piano for a telescope." — p. 100.

Why did not our author add the classical illustration, *Οὐ γὰρ σύριγγα κέρκου τοῦ χοίρου ποιητέον* ? Surely, the doctrine of an ancient *savant*, one Bottom, "The eye of man hath not heard, the ear of man hath not seen, man's hand is not able to taste, his tongue to conceive, nor his heart to report," — opposed although it has been in these Mesmeric days, — is now incontrovertibly established. Again:

> "The nervous and optical mechanism of the eye is so arranged as to have entire charge of the reception of impressions conveyed by the luminiferous ether; the auditory mechanism of the ear is constituted so as to receive undulations of gaseous bodies like atmospheric air; and, correspondingly, if intelligence has to be communicated to a distance, and received by other minds through the agency of a visual organ, the motor nerves of the hand are put in action, the fingers move, and letters appear upon the paper." — p. 101.

But the number of these letters is sometimes out of all proportion to the amount of intelligence communicated.